Effects of N fertilization on yield for low-input production in Spanish wheat landraces (*Triticum turgidum* L. and *Triticum monococcum* L.)

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Abstract

A core subset of Spanish durum wheat landraces was evaluated at two nitrogen levels (80 and 220 kg/ha) to identify landrace genotypes adapted to low N production. Yield differences were statistically significant between N levels and among genotypes at both levels. Fifty-one per cent of the landraces yielded significantly more at low than at high N (low-N varieties) while 26% had a positive (high-N varieties) and 23% an indifferent (indifferent-N varieties) response to N fertilizer. No significant agromorphological differences were found among low and high-N varieties at low N level that conferred some advantage to low-N varieties. In contrast, high-N varieties possessed longer grain-filling period under high N level. Phenological characters showed an important influence on yield and on the performance of the varieties within each subgroup. The traits affecting grain yield most positively, mainly the low-N varieties, were long filling period and earliness. Five entries were selected for prebreeding to low N adaptation.

Key words: *Triticum turgidum* ssp. *durum* — landraces — low-input — nitrogen — wheat — yield — core subset

Nitrogen (N) is an essential plant nutrient required for high yield in wheat. Fertilizer use, however, increases significantly economic risks for farmers and causes eutrophication of watercourses. For both economic and ecological reasons, it is necessary to combine strategic fertilizer use with nutrient-efficient crop cultivars. On the other hand, landraces possess a fair stability under low-yielding conditions. Some breeding programmes seek to combine the favourable adaptative traits of wheat landraces with the high yield potential of modern genotypes to produce varieties of high yield stability (Pecetti et al. 1994, Boggini et al. 1997). In this context, the search for traits of economic value in these germplasm collections is important. The cost and time linked to these studies are, however, significant impediments. Samples including those with high genetic variation (core subsets) can help for cost-effective evaluations and to find geographical areas as potential donors for breeding.

In this work, a set of durum wheat landraces was evaluated to identify genotypes adapted to low nitrogen production. Some traits were recorded to assess their suitability as selection criteria in prebreeding.

Materials and Methods

A core subset of the National Plant Genetic Resources Centre (CRF-INIA) was evaluated at two N levels under rainfed conditions during the season 2003–2004 at Alcalá de Henares, Madrid. The sample included 53 accessions of the Spanish durum wheat (*Triticum turgidum* ssp. *durum*) landraces, three Polish wheats (*Triticum turgidum* conv. *polonicum*), five emmers (*Triticum turgidum* ssp. *dicoccon*), one wild emmer (*Triticum turgidum* ssp. *dicoccoides*), and three einkorns (*Triticum monococcum* L.). Three durum wheat cultivars were used as test varieties: Senatore Capelli, an old cultivar released in Italy before 1930, Cocorit-71, a semidwarf cultivar released in Spain in1977 and Yavaros-79, one of the most cultivated varieties in Spain released in 1984. All the varieties were sown in a randomized-complete-block design with two treatments (varieties and N fertilizer) in November 2003. The seeding rate was 400 seeds per plot for both N levels. The harvested plot size was 1.5 m^2 (two rows, 2 m long, 37.5 cm apart) with a plot spacing of 112.5 cm. Nitrogen was applied at a rate of 40 kg/ha (8-24-8) prior to sowing. In February, two rates of N as ammonium nitrate were applied, 40 kg/ha in the low N level experiment and 180 kg/ha in the high N level experiment. All accessions were evaluated for the agromorphological characters: days to heading and to maturity, grain-filling period, plant height, spike length, spikelets per spike, lodging susceptibility (1–7), lodged plants (%) and lodging susceptibility × lodged plants. The variables were measured according to IBPGR (1985).

The data were analysed by a two-way ANOVA (test varieties not included). The interaction between treatments was tested by Tukey's test (Tukey 1949). The entries were clustered in subgroups according to their response to N fertilization (negative, positive, or indifferent) using least significant difference (LSD) from the ANOVA at $P = 0.01$. Relationships between variables were examined by Pearson correlation coefficients.

Results

Yield response of varieties at low and high N fertilization level

Yield differences were statistically significant between N levels ($F = 10.60$, $P \leq 0.01$) and among genotypes at both levels ($F = 80.95$, $P \leq 0.01$). The effect of N on grain yield varied among varieties, ranging from a large reduction to a large yield increase (212–887 at low N and 178–994 at high N). The genotype × fertilizer interaction was significant at $P = 0.10$ ($F = 2.70$). Hence, the varieties were separated and analysed according to their N response. Thirty-three out of 65 landraces, low-N varieties in the present work, yielded significantly more at low than at high N level (Table 1). In contrast, 17 varieties yielded significantly more at high than at low N (high-N varieties). A third subgroup of 15 entries showed no significant differences in yield between both N rates (indifferent-N varieties). The three subgroups of varieties showed wide range of variation for yield. The ANOVA carried out for each subgroup indicated that interactions between N

Table 1: Agromorphological traits with significant differences between low and high N fertilizer levels in the low-, high- and indifferent-N varieties and in the test varieties

	Low-N varieties			High-N varieties			Indifferent-N varieties			Senatore Capelli			Cocorit-71			Yavaros-79		
	Low N	High N	P-value	Low N	High N	P-value	Low N	High N	P-value	Low N	High N	P-value	Low N	High N	P-value	Low N	High N	P-value
Yield (g/plot)	590	450	**	500	600	**	485	482	NS	703	564	**	979	966	NS	852	922	**
Days to maturity (days)	228	229	**	228	229	NS	228	228	NS	231	231	NS	228	231	*	224	224	NS
Plant height (cm)	145	142	*	136	132	*	135	130	*	139	134	**	105	105	NS	95	100	**
Grain-filling period (days)	36	36	NS	37	40	*	37	37	NS	46	39	**	53	56	*	52	49	*
Days to heading (days)	192	193	NS	191	189	NS	189	191	*	185	192	**	175	175	NS	172	175	**

NS, *,**: non-significant, significant at P = 0.05 and P = 0.01 respectively.

level and cultivar were not significant while variation among genotypes was highly significant ($P \leq 0.01$). The emmer and Polish wheats performed like low- or indifferent-N varieties and the wild emmer like a low-N variety. Two einkorns performed like low-N varieties and one like a high-N variety. These wheats had low yields (from 212 to 764 at low N and from 220 to 670 at high N), high days to heading and short grain-filling periods.

The two subgroups with opposite N responses were compared at both N fertilizer rates (Table 2). The differences at low N were only significant for yield. In contrast, the high-N varieties had larger values of yield, lodging parameters and grain-filling period than low-N varieties at high N level.

N effects within each variety subgroup

Table 1 reports the traits for which the subgroup mean values differed between N levels. The low and indifferent-N varieties showed lower days to maturity and days to heading, respectively, at low than at high N while the high-N varieties had shorter grain-filling period at low N level. The three subgroups presented higher plant height at low N. No significant differences were found between lodging at both N rates in any of the three subgroups.

Significant relationships between yield and days to heading and some agro-morphological traits were detected in the three variety subgroups at both N rates (Table 3). Yield was both negatively and positively significantly correlated with days to heading and grain-filling period, respectively, mainly in the low-N varieties subgroup. In this subgroup yield was also negatively correlated with days to maturity at high N. In the three subgroups at the two N levels, days to heading was negatively correlated with grain-filling period and positively with days to maturity and plant height (except in the high-N varieties at low N). In the high-N varieties, the number of spikelets per spike showed a negative association with yield and positive association with days to heading at both N rates. This last positive correlation was also found in the indifferent-N varieties at low N. Highly significant correlations between N levels were obtained for yield (0.87 for low-N varieties, 0.96 for high-N varieties and 0.99 for indifferent-N varieties) and all the agromorphological traits, except for the lodging parameters, in the three variety subgroups (results not shown).

The test varieties Senatore Capelli, Yavaros-79 and Cocorit-71 performed like a low-, high- and indifferent-N variety respectively. Senatore Capelli had the lowest yield and the highest values for height and days to heading and the shortest for grain-filling period at both N rates. In contrast, Cocorit-71 and Yavaros-79 are early varieties with long filling periods (Table 1).

Discussion

Yield response to applied N fertilizer differed among the 65 wheat landraces studied. These differences indicated that the effect of N on grain yield depended on the genotype as in the studies of Gauer et al. (1992), Fischer et al. (1993), van Herwaarden et al. (1996) and Cooper et al. (2001) with bread wheat, and Boggini et al. (1997) with durum wheat. Conversely, van Sanford and MacKown (1986) and Entz and Fowler (1989) found no significant genotype × environment interaction for grain yield in bread wheat. The fact that the yield of low-N varieties at low N level was similar to that obtained with the high-N varieties at high N level (Table 1) indicated that there were landraces that required less nitrogen to produce the same yield. Ortiz-Monasterio et al. (1997)

Table 2: Significant differences between low and high-N varieties subgroups at low and high N fertilizer levels

	Low N level			High N level		
	Low-N varieties	High-N varieties	P-value	Low-N varieties	High-N varieties	P-value
Yield (g)	590	500	*	450	600	**
Lodging susceptibility	5	5	NS	4	5	*
Lodged plants (%)	49	53	NS	47	66	*
Lodging × lodged plants	245	296	NS	217	407	**
Grain-filling period (days)	36	38	NS	36	40	*

NS, *,**: non-significant, significant at P = 0.05 and P = 0.01 respectively.

Table 3: Correlation coefficients between yield and days to heading and the agromorphological traits in the three subgroups of varieties at both N fertilizer levels

	Low-N varieties (n = 33)		High-N varieties (n = 17)		Indifferent-N varieties (n = 15)	
	Low N	High N	Low N	High N	Low N	High N
Yield vs.						
Days to heading	−0.43*	−0.56**	−0.43 NS	−0.52*	−0.21 NS	−0.12 NS
Grain-filling period	0.32 NS	0.55**	0.26 NS	0.37 NS	0.72**	0.26 NS
Days to maturity	−0.19 NS	−0.35*	−0.29 NS	−0.43 NS	0.27 NS	0.07 NS
Spikelets per spike	0.18 NS	0.02 NS	−0.55*	−0.61**	−0.16 NS	−0.02 NS
Days to heading vs.						
Days to maturity	0.51**	0.74**	0.41 NS	0.56*	0.66**	0.85**
Plant height	0.56**	0.70**	0.36 NS	0.60**	0.57*	0.75**
Grain-filling period	−0.68**	−0.88**	−0.78**	−0.86**	−0.63*	−0.88*
Spikelets per spike	0.13 NS	0.18 NS	0.52*	0.62**	0.64*	0.47 NS

NS, *,**: non-significant, significant at P = 0.05 and P = 0.01 respectively.

showed that under low N levels in the soil, N use efficiency increased mainly due to a higher N uptake (ability of plants to absorb N) whereas under high N levels, the increase was the N utilization (capacity of plants to convert N into grain yield). According to that, low-N varieties would have superior N uptake efficiency than the rest. The best performing lines at both N levels possibly had compensation between both components under different N conditions.

The differences in yield between low-N and high-N varieties were lower at low N level than at high N level (Table 2). This could be due to the varieties analysed are landraces adapted to a low-input agriculture. It was not found any significant agromorphological differences between low and high-N varieties at low N level that conferred some advantage to low-N varieties. In contrast, high-N varieties possessed longer filling period than low-N varieties under high N level (Table 2). The yield depression from high N supply in low-N varieties was not related to lodging in agreement with Entz and Fowler (1989). One study in the field and controlled environments has shown reductions in yield with the addition of N fertilizer (van Herwaarden et al. 1996). The authors regarded this phenomenon as 'haying-off' which seemed to affect the low-N varieties analysed in the present work.

Phenological characters showed an important influence on yield and on the performance of the varieties within each subgroup. The effect of N in low-N varieties was a delay in maturity in addition to grain yield depression (Table 1). Turk and Tawaha (2002) also showed that N fertilizer prolonged the vegetative growing period of irrigated winter wheat. van Herwaarden et al. (1996) suggested that the problem of haying-off could be associated with a delay in maturity and/or high tillering at high N level. It is possible that the delay of heading stimulated by N in low N varieties increased tillering and reduced grain weight (Oscarson 2000, Turk and Tawaha 2002). In the high-N varieties, the most important fertilizer effect was an increase of the length of the grain-filling period (Table 1).

The traits affecting grain yield most positively, mainly in low-N varieties, were long filling period and earliness (Table 3). In high-N varieties, earliness was directly associated with yield at high N level and indirectly at low N level. The positive correlation between days to heading and spikelets per spike indicated that early varieties had fewer spikelets per spike, which were correlated with higher yield at both N levels (Table 3). The reduced yields associated with the emmers, einkorns and polish wheats could be due to the short filling periods and delays in heading. Worland et al. (1998) found that earliness alleles can reduce spikelet numbers and produce larger grain and greater yield in southern Europe. Earliness in heading and long filling period were also important factors to achieve good yields in the test varieties. The most modern high-yielding cultivar Yavaros was the most penalized by low N while the obsolete cultivar Cocorit had the best yield at both N levels (Table 1).

In comparison with test varieties, no landrace outyielded Cocorit at low N level, but 12 performed better than Senatore Capelli and three outyielded Yavaros. At high N level, one landrace outyielded Yavaros and Cocorit. In contrast, Laing and Fischer (1977) and Ortiz-Monasterio et al. (1997) reported that the semidwarf cultivars outyielded the old tall cultivars with or without high productivity conditions. In our evaluation several landraces with height from 103 to 156 cm outyielded the semidwarf cultivar Yavaros, indicating that landraces and old cultivars can provide sources of genetic variation to increase yield stability under limited N use.

For breeding to low N adaptation, the selection should be focussed on the best-yielding varieties at low N level (> 800 g per plot). Five entries were selected: three low-, one high- and one indifferent-N varieties. These landraces had superior and consistent yield at both N rates, showing that the top-yielding varieties had good performances at both N conditions. van Herwaarden et al. (1996) found a reversal of variety rankings for yield at contrast N rates suggesting the importance of evaluating varieties at a representative level of fertility. Our results in agreement with Pecetti et al. (1992) who showed that durum wheat genotypes selected under unfavourable conditions were able to retain its superiority in a more favourable environment. In the present experiment, a selection criterion for low N adaptation could be established based on minimum values for grain-filling period and days to heading and maturity, the traits most affecting yield. These minimum values were those obtained by Senatore Capelli at high N level (Table 1) where a large decrease in yield was detected. The five superior genotypes previously selected achieved all these values. These landraces come from the Centre-South of Spain where earliness is desirable.

Several authors have related yield stability under drought and low N conditions (van Herwaarden et al. 1996, Reeves 1998). Our results are in agreement with this statement since earliness of heading is also an essential mechanism under drought conditions (Pecetti et al. 1994). Consequently, the durum wheat landraces analysed in the present work could be a reservoir of widely adapted germplasm for sustainable low-input production. It was also shown that core subsets of germplasm collections constitute a helpful tool to preselected genotypes for breeding programmes.

Acknowledgements

Financial support came from the projects RF-04-018 from INIA, AGL 2003-6382 from CICYT and the INIA predoctoral grant for E. Aguiriano.

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